

# Assemble, Flying And Performance Evaluation Of Quadcopter (UAV) For Agriculture Application

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**Abstract-** *Unmanned Aerial Vehicles (UAVs) have gained significant importance in both military and civilian applications worldwide in recent years. However, their design involves complex optimization of multiple parameters and engineering decisions. This paper presents a comprehensive approach to the design, manufacturing, and performance evaluation of an electrically powered radio-controlled quadcopter drone, aimed at achieving stable take-off, efficient cruise flight, safe landing, and maximum payload carrying capacity.*

*The development process includes several stages: conceptual design, structural analysis, performance analysis, material selection, fabrication, and experimental testing. The quadcopter was designed with an empty weight of 15.43 lbs and a maximum take-off weight of 33.07 lbs. The system achieved a maximum (flight) height of 220m, an operational range of 2-4km, and a lift/payload capacity of 40 lbs. Additionally, the drone demonstrated a cruising speed of 46 ft/s and a maximum speed of 78 ft/s, with a controlled take-off distance equivalent to standard multirotor vertical lift characteristics.*

*Experimental results indicate that the proposed design provides stable flight performance, efficient payload handling, and reliable operation under varying conditions. This study contributes to the development of cost-effective and high-performance UAV systems suitable for real-world applications such as surveillance, agriculture, and delivery.*

## I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have emerged as an important technological advancement in recent years, particularly in the field of agricultural engineering. Although aeronautical engineering as a discipline is relatively modern, the concept of flight has evolved significantly, leading to the development of compact, efficient, and application-oriented aerial systems such as quadcopters.

UAVs are defined as powered aerial vehicles that operate without an onboard human pilot, utilizing aerodynamic forces and propulsion systems to achieve lift and controlled motion. These systems can be operated either autonomously or through remote control and are capable of carrying various payloads depending on the application. Among different UAV types, quadcopters—belonging to the multi-rotor category—have gained widespread attention due to their simple mechanical structure, vertical take-off and landing (VTOL) capability, high maneuverability, and suitability for low-altitude operations.

In the context of agricultural engineering, quadcopter UAVs play a crucial role in enhancing precision farming practices. They are extensively used for applications such as crop monitoring, pesticide spraying, irrigation assessment, soil analysis, and yield estimation. These drones provide rapid data acquisition, reduce human effort, and improve operational efficiency, especially in areas that are difficult to access using conventional methods.

UAVs can be broadly classified based on their aerodynamic configuration into fixed-wing, flapping-wing, ducted fan, and multi-rotor systems. Additionally, based on their take-off and landing mechanisms, they are categorized into horizontal take-off and landing (HTOL) and vertical take-off and landing (VTOL) systems. Quadcopter drones fall under the VTOL multi-rotor category, making them highly suitable for agricultural applications where space constraints and precision are critical.

Despite their advantages, the design and development of quadcopter UAVs involve several challenges, including optimization of weight, payload capacity, flight stability, energy efficiency, and cost. Achieving a balance between these parameters while ensuring reliable performance is a complex engineering task.

Motivated by these challenges and the growing demand for efficient agricultural solutions, this research focuses on the design, assembly, flying, and performance testing of a quadcopter drone. The objective is to develop a robust, cost-effective UAV system capable of stable flight and efficient payload handling for agricultural applications.

## II. METHODOLOGY

The methodology adopted in this research focuses on the systematic design, development, and evaluation of a quadcopter UAV for agricultural applications. The overall process includes component selection, system integration, fabrication, and experimental validation.

### A. System Architecture

The quadcopter system consists of mechanical, electrical, and control subsystems integrated to achieve stable flight and efficient payload handling. The major components include:

- Frame structure (to support all components)
- Brushless DC motors (to generate thrust)
- Electronic Speed Controllers (ESCs) (to regulate motor speed)
- Flight controller (for stabilization and control)
- Battery (power source)
- Radio transmitter and receiver (for communication)
- Sensors (IMU, GPS for navigation and stability)
- Payload unit (agricultural spraying mechanism)

All components were interconnected to form a complete UAV system capable of controlled flight and data acquisition.

### B. Component Selection

Component selection was carried out based on performance requirements such as payload capacity, flight time, and efficiency. The selection criteria included:

- **Motors and Propellers:** Chosen based on required thrust-to-weight ratio (>2:1)
- **Battery:** Selected to provide sufficient power for desired flight endurance
- **Frame:** Lightweight and (strong) to withstand structural loads
- **Flight Controller:** Capable of real-time stabilization and control

Manufacturer specifications and simulation data were used to ensure compatibility and optimal performance.

### C. Assembly and Integration

The quadcopter was assembled by mounting all components onto the frame and establishing proper electrical connections. The integration process involved:

- Fixing motors and propellers to the frame
- Connecting ESCs to motors and flight controller
- Power distribution from battery to all components
- Installing sensors and communication modules

Special care was taken to ensure proper alignment, secure connections, and balanced weight distribution for stable flight.

### D. Flight Control and Calibration

The flight controller was configured to manage the quadcopter's motion through sensor feedback. Calibration procedures included:

- IMU calibration (accelerometer and gyroscope)
- ESC calibration (for uniform motor response)
- Radio transmitter calibration

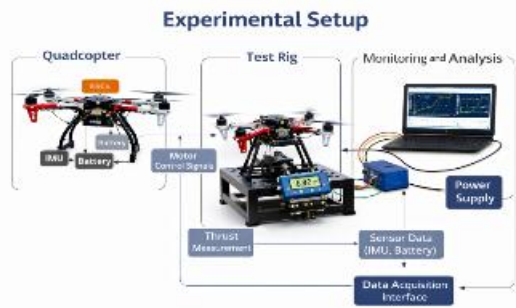
The control system continuously adjusts motor speeds to maintain stability in **roll, pitch, and yaw axes** during flight.

### E. Experimental Setup

Experimental testing was conducted to evaluate the performance of the quadcopter under different operating conditions. The setup included:

- Thrust measurement using a test rig
- Flight testing in open-field conditions
- Payload testing for agricultural applications

Environmental factors such as wind speed and temperature were also considered during testing.



## F. Data Collection and Analysis

Performance data were collected during experiments and analyzed to evaluate system efficiency. The parameters measured include:

- Flight time (endurance)
- Payload capacity
- Power consumption
- Stability performance

The collected data were processed and represented using graphs and tables to identify trends and validate system performance.

## G. Performance Evaluation

The quadcopter performance was evaluated based on:

- Ability to achieve stable hovering
- Payload lifting capability
- Energy efficiency
- Response to external disturbances

The results obtained were compared with theoretical expectations to assess the effectiveness of the design.

## III. CONCEPTUAL DESIGN

### A. Wing shape and mounting position:

The tapered wing in combination with the multi-element propeller had issues that directly affected flight safety due to difficulty of mounting the second element accurately on its designed axis, leading to unsymmetric control surface deflections, so an early decision was made to Favor a rectangle wing with a suitable wingtip to reduce induced drag [Table 1]. Despite the low difference between the high and medium wing options in [Table 2], the high wing was

Favourable to increase stability, safety during take-off and landing, and maintaining cargo reachability for easy loading and unloading.

### B. engine, Propeller, and landing gear configurations:

A single puller motor was chosen over pusher for forward C.G and better stability [Table 3]. A 2-blade constant pitch propeller was chosen over 3-blade propeller due to higher efficiency and less over consumption to satisfy power limitations with fiberglass material to decrease weight . Tricycle was Favoured to tail dragger landing gear because of the following properties, provided dynamically stable on the ground so it is easier to manoeuvre, good ground control at crosswinds, hard braking on the main wheels cannot cause the airplane to nose over, less bounce after touch-down, good acceleration during take off due to lower AOA, shorter wheel base permits tight turning radius and easier to land.

Table 1

Comparative analysis of wing planforms

Criteria	weighting	Tapered shape	Midway taper shape	Elliptical shape
Lift coefficient	0.35	0.7	0.9	0.74
manufacturing	0.3	0.8	0.85	0.85
Induced drag	0.2	0.83	0.95	0.89
Wing weight	0.15	0.89	0.9	0.95
Total	1	0.7845	0.8950	0.8345

Table 2

Comparative analysis of wing mounting position

Criteria	weighting	High wing	Mid wing	Low wing
Stability	0.3	0.9	0.8	0.95
Ground effect	0.4	0.8	0.75	0.95
Ground clearance	0.2	0.7	0.95	0.95
Structured weight	0.1	0.9	0.85	0.85
Total	1	0.820	0.815	0.940

Table 3

Comparison of engine configuration

Criteria	weighting	Puller	pusher
Efficiency	0.4	0.85	0.65
Drag	0.3	0.8	0.75
Safety	0.2	0.75	0.85
Downwash on tail	0.1	0.85	0.55
Total	1	0.785	0.7

#### IV. INITIAL DESIGN POINT AND DESIGN SPACE

To determine the initial design configuration and acceptable operating region, a constraint-based analysis was carried out. The analysis considered key mission parameters such as **payload capacity, flight time (endurance), rate of climb, cruising speed, and stability requirements**. These parameters were evaluated as functions of **thrust-to-weight ratio (T/W)** and **power-to-weight ratio**, which are critical for multirotor systems.

A design selection graph was developed using MATLAB to identify feasible operating conditions. Based on the analysis, an initial design point was selected to achieve

**optimal thrust generation with minimum power consumption**, ensuring efficient payload carrying capability and stable flight performance. The chosen configuration provides a balance between **lifting capacity, energy efficiency, and structural weight**, which is essential for agricultural applications.

#### A. Weight Estimation

Weight estimation was performed during the early design stage using empirical methods. The total weight of the quadcopter includes:

- Frame weight
- Motors and propellers
- Electronic Speed Controllers (ESCs)
- Flight controller and sensors
- Battery
- Payload (e.g., spraying mechanism)

These values were incorporated into a simulation model to improve design accuracy and system performance prediction.

### V. DETAILED DESIGN

In the detailed design phase, the system configuration was finalized, and the design parameters were fixed. This stage marked the transition from conceptual design to the **fabrication and assembly phase** of the quadcopter.

#### A. Propulsion System Design

##### i) Motor and Propeller Selection:

The propulsion system is a critical component of a quadcopter, directly affecting lift generation, stability, and efficiency. Key parameters considered include:

- Thrust requirement
- Power consumption
- Propeller diameter and pitch
- Motor KV rating

High-efficiency propellers and motors were selected to ensure sufficient thrust for **vertical take-off and payload lifting**, especially under agricultural operating conditions. Performance analysis was conducted using simulation tools and manufacturer data to determine optimal combinations.

##### ii) Performance Evaluation of Propellers

Different propeller configurations were analysed to evaluate their effect on:

- Thrust generation
- Power efficiency
- Stability during hovering

Low-speed, high-thrust propellers were preferred, as they provide better lifting capability and improved efficiency for agricultural spraying applications.

## B. Multi-Rotor Configuration

The quadcopter uses a **four-rotor configuration**, where each rotor contributes to lift and control. The arrangement ensures:

- Stable hovering
- Precise maneuverability
- Redundancy and control efficiency

The interaction between propellers and airflow was considered to minimize turbulence and improve overall system performance.

In quadcopter systems, structural analysis is essential to ensure that the frame and components can withstand various operational loads during flight. Unlike fixed-wing aircraft, quadcopters are primarily subjected to loads generated by **thrust, payload, vibrations, and maneuvering forces**.

The structural evaluation was carried out by considering critical loading conditions such as:

- Maximum take-off weight
- Payload-induced stress
- Thrust forces generated by motors
- Dynamic loads during ascent, descent, and maneuvering

A safe **thrust-to-weight ratio (T/W)** was selected to ensure stable flight and structural reliability. For effective operation, the quadcopter was designed to maintain a thrust-to-weight ratio greater than **2:1**, which provides sufficient lift margin for payload carrying and control stability.

## VI. STRUCTURAL ANALYSIS

### A. Operating Envelope

Instead of a conventional flight envelope used in fixed-wing aircraft, the operating limits of the quadcopter are defined based on its **flight performance and structural constraints**.

Key operating parameters considered include:

- **Maximum altitude:** Defines the safe operating height of the drone
- **Maximum forward speed:** Limited by stability and control response
- **Rate of climb and descent:** Determines vertical performance
- **Payload capacity:** Affects structural stress and flight stability

The maximum forward speed of the quadcopter was maintained within a safe limit to ensure controlled maneuverability and minimize structural stress. Similarly, the payload limit was selected based on the frame strength and motor thrust capacity.

These parameters were used to evaluate critical operating conditions and ensure that the quadcopter structure can safely withstand all expected loads during flight.

### B. Performance Analysis

#### i) Aerodynamic and Thrust Analysis

Accurate aerodynamic and thrust analysis is essential for predicting the performance of a quadcopter UAV. Unlike fixed-wing aircraft, where drag plays a dominant role, quadcopters primarily rely on **thrust generated by propellers** to overcome gravitational and aerodynamic forces.

In this study, the performance of the quadcopter was evaluated by analysing **thrust generation, power consumption, and aerodynamic losses**. The total thrust produced by the motors must be sufficient to balance the **weight of the drone (including payload)** and overcome minor aerodynamic drag during motion.

Computational tools such as **ANSYS** and **Sim Scale** were used to analyse airflow behaviour around the propellers and frame. These simulations helped in estimating:

- Thrust efficiency
- Airflow distribution
- Effect of turbulence on performance

The analysis ensured that the selected propulsion system provides adequate thrust while maintaining energy

efficiency, which is critical for agricultural operations requiring longer flight duration.

**ii) Take-off and Landing Performance**

For quadcopters, take-off and landing are achieved through **vertical lift**, unlike fixed-wing aircraft that require a runway. Therefore, performance is evaluated based on **thrust capability and stability** rather than take-off distance.

The take-off condition is satisfied when the **total thrust exceeds the total weight of the quadcopter**. The developed system was tested under both no-load and full-load conditions to evaluate lifting performance.

Key observations include:

- Under no-load conditions, the quadcopter achieved stable lift with lower power consumption
- Under full payload conditions, higher thrust and power were required for vertical take-off
- Smooth and controlled landing was achieved by gradually reducing motor speed

Environmental factors such as **wind speed and ambient temperature** were also considered, as they influence flight stability and power requirements. Increased wind speed results in higher power consumption to maintain stable hovering.

**C. Power System Performance**

**i) Hovering and Forward Flight**

The power system performance of the quadcopter was analyzed by evaluating its behavior during **hovering (stationary flight)** and **forward motion**.

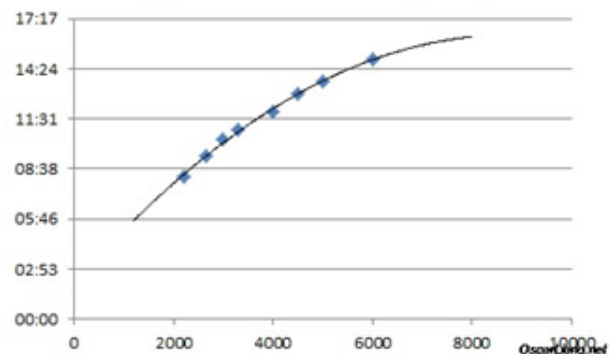
- **Hovering condition:** Occurs when the total thrust is equal to the weight of the quadcopter. This is a CRITICAL operating condition for agricultural applications such as spraying. The power required for hovering was calculated and used to estimate flight endurance.
- **Forward flight condition:** Requires additional thrust to overcome aerodynamic resistance and maintain motion. As speed increases, power consumption also increases due to higher drag and airflow disturbances.

The relationship between **thrust, power consumption, and velocity** was analyzed to determine:

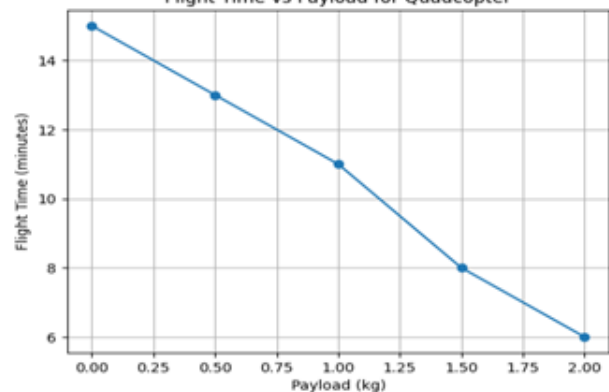
- Maximum achievable speed
- Optimum operating speed (for minimum power consumption)
- Efficient working range for agricultural tasks

The results indicate that the quadcopter operates most efficiently at moderate speeds, where power consumption is minimized while maintaining stable flight.

**Flight Time VS Bat Capacity**



**Flight Time vs Payload for Quadcopter**



**ii) Static and Dynamic Thrust**

Static and dynamic thrust tests were conducted to evaluate the lifting capability and performance of the quadcopter propulsion system.

- **static thrust** refers to the thrust produced by the propellers when the drone is stationary (hover condition).
- **Dynamic thrust** refers to the thrust generated during actual flight conditions when the drone is in motion.

A test rig was used to measure the thrust generated by the motor-propeller combination. The measured thrust values were compared with theoretical calculations to validate system performance.

The results showed that the available thrust exceeded the required thrust for take-off, ensuring safe and stable operation. This confirms that the quadcopter can generate sufficient lift to carry the intended payload under real operating conditions.

### iii) Stability Analysis

Stability in a quadcopter is achieved through the flight controller and sensor feedback system rather than aerodynamic surfaces as in fixed-wing aircraft

The stability of the quadcopter was evaluated based on:

- **Hover stability** (ability to maintain position)
- **Response to disturbances** (wind or external forces)
- **Control inputs** (roll, pitch, yaw movements)

Sensor data from the **IMU (Inertial Measurement Unit)**, including accelerometer and gyroscope readings, were used to maintain stability through real-time corrections.

The quadcopter demonstrated stable hovering and smooth response to control inputs, indicating effective stabilization. Minor disturbances were quickly corrected by the control system, ensuring reliable flight performance.

Dynamic stability was further verified through test flights, where the drone maintained controlled motion without excessive oscillations or drift.



## VII. RESULTS AND DISCUSSION

The developed quadcopter UAV was experimentally evaluated to assess its performance in terms of flight stability, payload handling, thrust capability, energy efficiency, and structural reliability. The results obtained from various tests were analyzed and compared with the design expectations to validate system effectiveness for agricultural applications.

### A. Flight Performance Evaluation

The quadcopter exhibited stable and controlled flight under varying operating conditions, including no-load and full-load scenarios. The system successfully achieved **vertical take-off, steady hovering, controlled maneuvering, and safe landing**.

The stability observed during flight can be attributed to the effective tuning of the flight controller and accurate sensor feedback from the IMU. The drone maintained consistent orientation with minimal drift, even under minor environmental disturbances such as wind.

These results confirm that the developed system satisfies the fundamental flight requirements necessary for precision agricultural operations, where stable hovering is critical for uniform spraying and monitoring.

### B. Payload–Endurance Trade-off Analysis

A detailed analysis of payload versus flight time was conducted to evaluate the endurance characteristics of the quadcopter. The results, as illustrated in the corresponding graph, indicate a **nonlinear decrease in flight time with increasing payload**.

This behavior is primarily due to the increased thrust demand required to lift additional weight, which results in higher current draw and faster battery depletion. At higher payload levels, the motors operate closer to their maximum capacity, reducing overall efficiency.

The findings highlight a critical design trade-off:

- **Higher payload capacity → Reduced flight endurance**
- **Lower payload → Improved efficiency and longer flight time**

For agricultural applications, this trade-off must be optimized based on mission requirements such as field size and spraying volume. Operating the quadcopter within an optimal payload range ensures maximum coverage with minimal energy consumption.

### C. Thrust and Propulsion Performance

The propulsion system was evaluated through static and dynamic thrust testing to ensure adequate lifting capability. The results confirmed that the **available thrust exceeds the required thrust under all operating conditions**, maintaining a thrust-to-weight ratio greater than 2:1.

This excess thrust margin provides:

- Improved flight stability
- Better control response
- Capability to handle sudden load variations

Furthermore, the motor–propeller combination demonstrated efficient thrust generation with minimal energy loss, validating the design selection. The thrust performance is particularly important in agricultural drones, where payload variation is frequent.

#### D. Energy Consumption and Efficiency Analysis

The energy performance of the quadcopter was analyzed by observing power consumption under different flight conditions.

- Hovering required relatively constant power to balance the drone’s weight
- Forward motion increased power consumption due to aerodynamic resistance
- Payload addition significantly increased current draw

The analysis revealed that the quadcopter operates most efficiently at **moderate thrust levels**, where the balance between lift generation and energy consumption is optimized.

These findings suggest that efficient mission planning—such as minimizing unnecessary payload and optimizing flight paths—can significantly improve operational efficiency.

#### E. Structural Performance and Reliability

Structural testing results confirm that the quadcopter frame is capable of withstanding operational and impact loads.

- The **three-point bending test** showed low deflection, indicating good stiffness
- Frame loading tests demonstrated acceptable deformation within elastic limits
- Drop tests verified impact resistance and structural durability

The minimal permanent deformation observed after loading indicates that the structure maintains its integrity under repeated use. This is critical for agricultural environments, where drones are subjected to frequent handling and varying load conditions.

#### F. Stability and Control Characteristics

The stability of the quadcopter was evaluated through real-time flight testing and response analysis.

- The system maintained stable hovering with minimal oscillations
- Rapid correction of disturbances was observed
- Smooth response to roll, pitch, and yaw inputs was achieved

The closed-loop control system, supported by sensor feedback, ensures continuous correction of attitude errors, resulting in reliable and stable flight behavior.

This level of stability is essential for applications such as **precision spraying**, where consistent positioning directly affects performance accuracy.

#### G. Critical Discussion and Limitations

Although the quadcopter demonstrated satisfactory performance, certain limitations were identified:

- Flight endurance decreases significantly with increased payload
- Battery capacity limits long-duration operations
- Efficiency drops at higher thrust levels

These limitations indicate the need for further optimization in:

- Battery technology
- Lightweight structural design
- Advanced energy management systems

#### H. Overall System Performance

The overall experimental results validate that the developed quadcopter meets the intended design objectives. The system demonstrates:

- Reliable and stable flight performance
- Adequate thrust for payload lifting
- Structural robustness under operational loads
- Acceptable energy efficiency for agricultural use

The integration of design, control, and testing ensures that the quadcopter is suitable for practical deployment in precision agriculture.

## VII. CONCLUSION

Unmanned Aerial Vehicles (UAVs), particularly quadcopters, are increasingly used in various real-world applications such as **crop monitoring, pesticide spraying, surveillance, and delivery systems**. This research work focused on the design, assembly, and performance evaluation of a quadcopter UAV for agricultural applications. The development process included **conceptual design, preliminary design, detailed design, fabrication, and testing**. Each phase contributed to optimizing system performance, structural strength, and operational efficiency.

The quadcopter was successfully designed and fabricated to achieve **stable vertical take-off, controlled flight, and safe landing**. The system demonstrated effective payload carrying capability and reliable performance under different operating conditions.

Experimental results confirmed that the quadcopter maintains:

- Stable hovering and maneuverability
- Adequate thrust-to-weight ratio for payload lifting
- Structural integrity under loading and impact conditions

The developed system operates efficiently within the designed power limits and provides a **cost-effective solution for agricultural applications**, particularly in precision farming and spraying operations.

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